Identifying coral refugia from observationally-weighted climate model ensembles

Peter Kalmus[1], Ayesha Ekanayaka[2], Emily Kang[2], Mark Baird[3], Michelle Gierach[1]

[1]NASA Jet Propulsion Laboratory; [2]University of Cincinnati; [3]Commonwealth Scientific and Industrial Research Organisation

Acknowledgments

Jet Propulsion Laboratory
California Institute of Technology

Mark Baird
CSIRO

Michelle Gierach
NASA/JPL

Peter Kalmus (PI)
NASA/JPL

Emily Kang
University of Cincinnati

Ayesha Ekanayaka
University of Cincinnati

Coral science

Data science and statistics

We gratefully acknowledge ongoing support from the NASA Biodiversity and Ecological Conservation program.

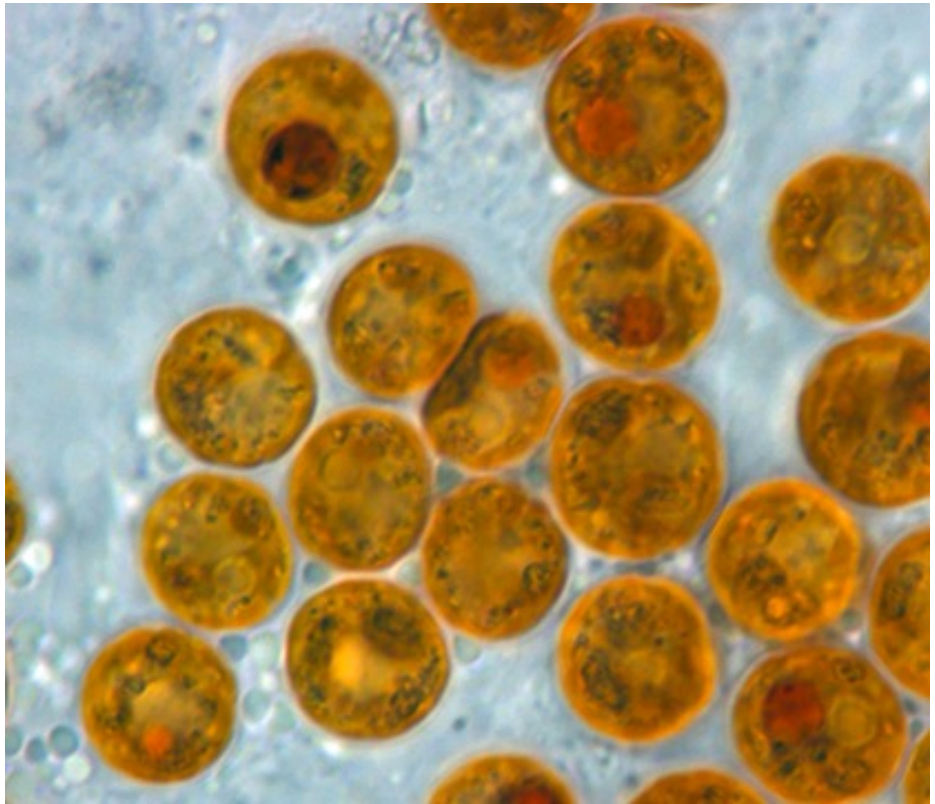
Corals bleach in ocean heatwaves

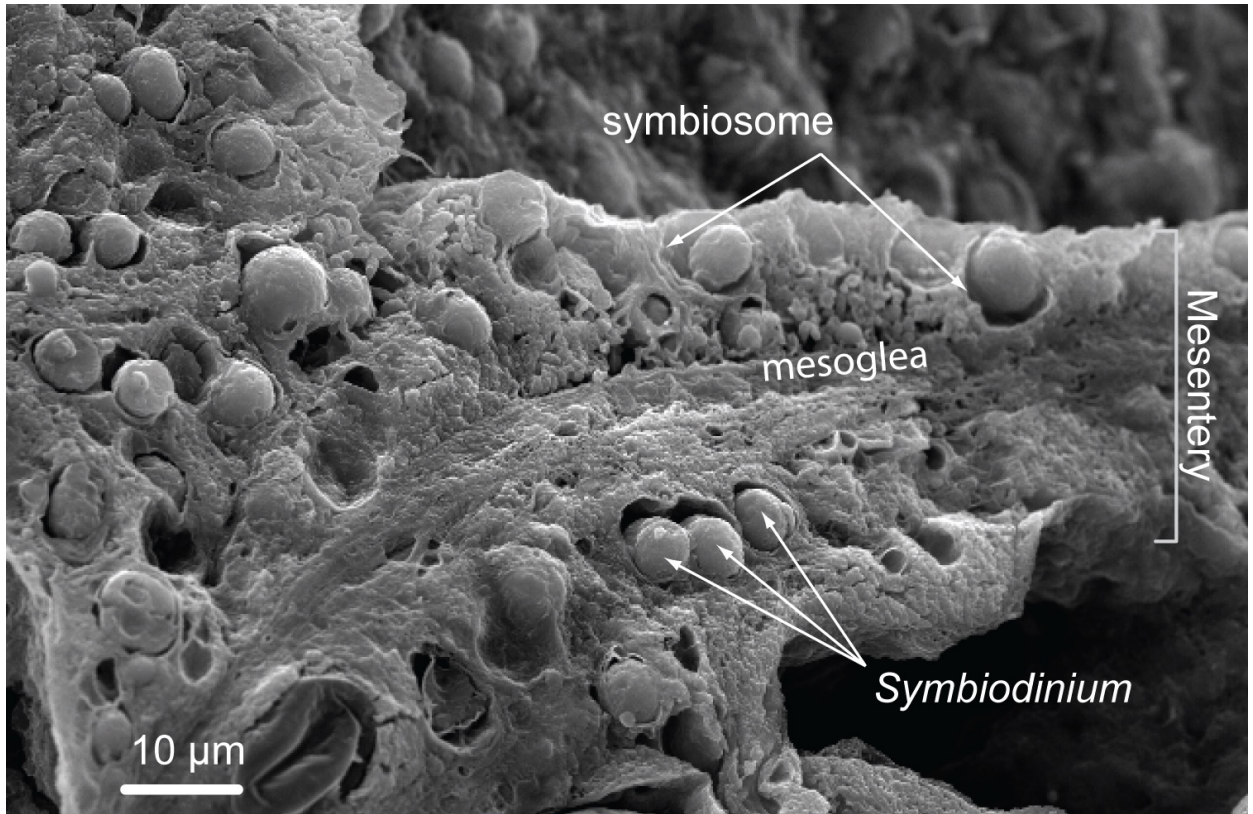
Jet Propulsion Laboratory
California Institute of Technology

Anomalous ocean heat can cause:

- thermal death
- bleaching and increased disease susceptibility
- bleaching and starvation

Recovery after severe bleaching requires 7+ years (Johns et al., 2014)





Overview

Jet Propulsion Laboratory
California Institute of Technology

- 34 CMIP6 model SST timeseries homogenized to 1° monthly grid
  - 4 climate scenarios: SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5
- Apply observational model weighting to the CMIP6 ensemble
- Statistically downscale ensemble weighted means using the JPL MUR 1 km SST
  - available 2002 - near present
- Calculate Degree Heating Weeks (DHW) from these time series
  - Relative to mean monthly maximum at each point
  - We use 3 climatological baselines:
    - 1988, the original CRW DHW formulation (Heron et al., 2014)
    - 1998, an update (Liu et al., 2014)
    - 2008, the MUR centroid
  - Perform 3-month running mean and multiply by 4.34 to convert from months to weeks
- We determine year after which every subsequent 5-year and 10-year period contains an ocean heat event above the 8 °C-week thermal threshold

Last year: Kalmus et al. (2022), Earth's Future
"Past the Precipice? Projected Coral Habitability Under Global Heating"

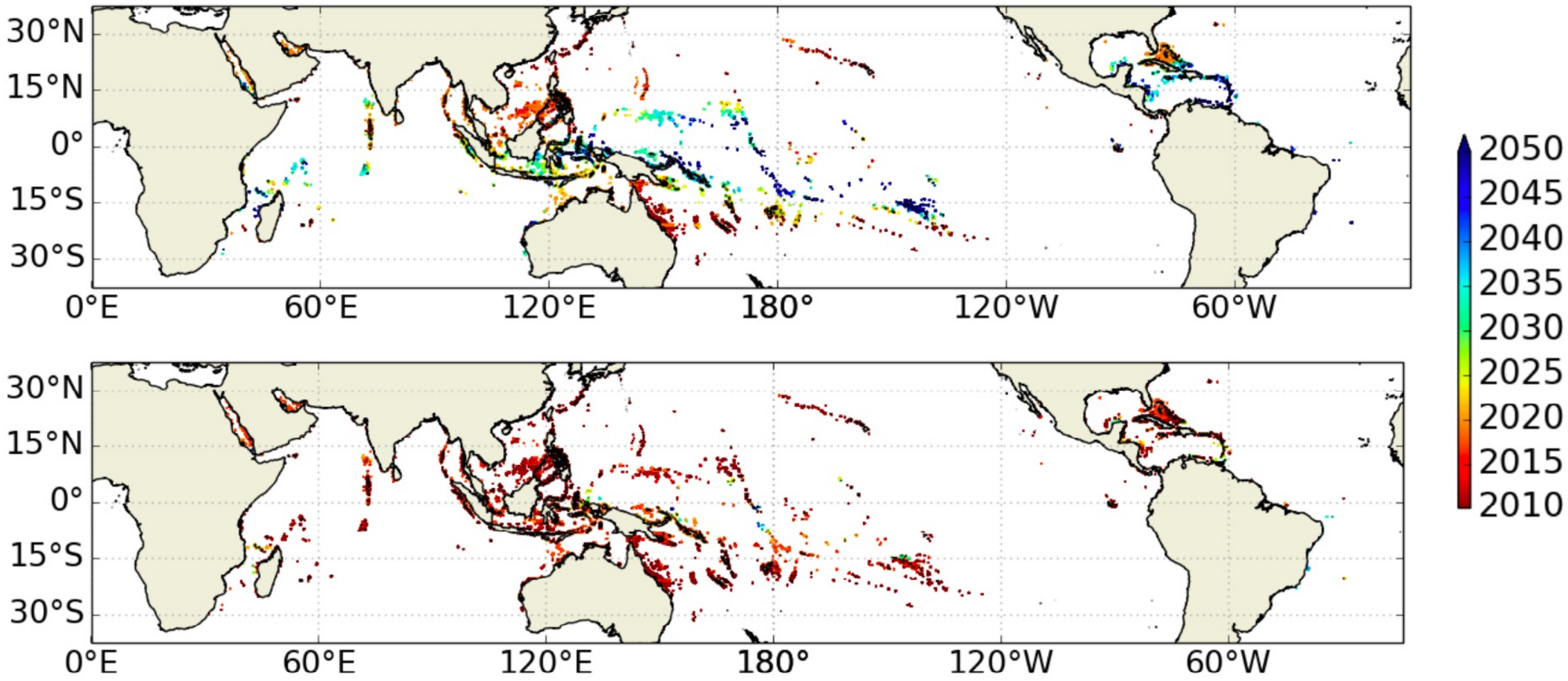
Key Points:

- We project over 91 percent of coral reefs will now experience severe-bleaching-level ocean heat recurring at least once every 10 years
- We project over 99 percent of reefs will experience severe-bleaching-level ocean heat at least twice per ten years by 2036 under SSP3-7.0
- We find SSP1-2.6 to be the only scenario not consistent with near-complete global severe degradation or loss of coral reefs

This year: Adding model weighting to the projections

Global maps of thermal departure

Jet Propulsion Laboratory
California Institute of Technology



(top) Highest thermal threshold, aggressive mitigation: TD5Y, 8 DHW2008, SSP1-2.6
(bottom) Lowest thermal threshold, aggressive fossil fuels: TD10Y, 8 DHW1988, SSP5-8.5

Model Weighting

Jet Propulsion Laboratory
California Institute of Technology

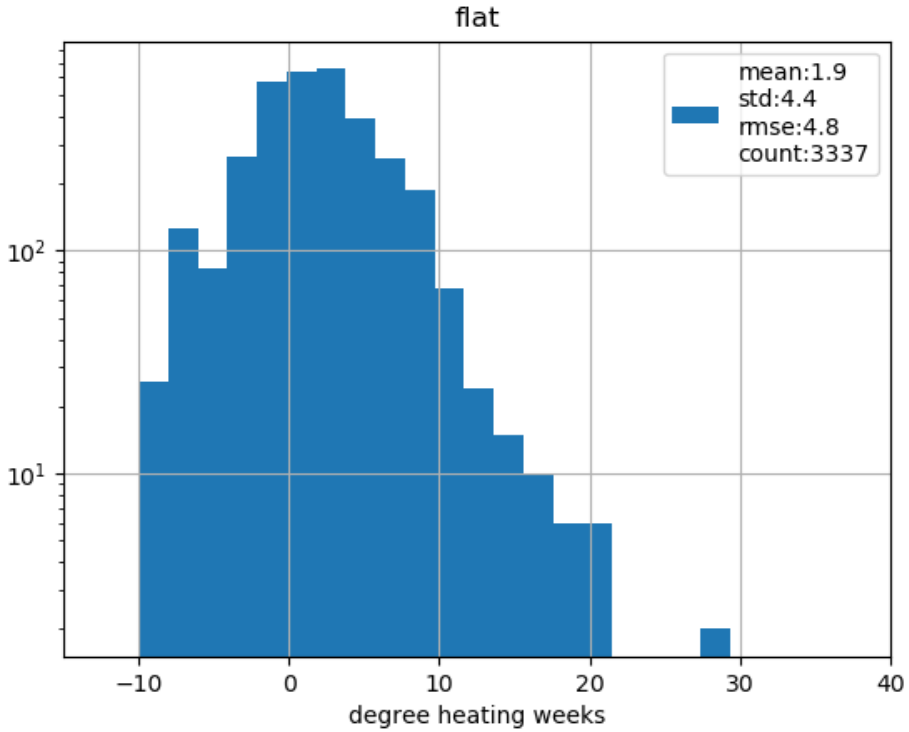
Compare each SST time series to observations (HadISST), for K models, N 1° reef locations

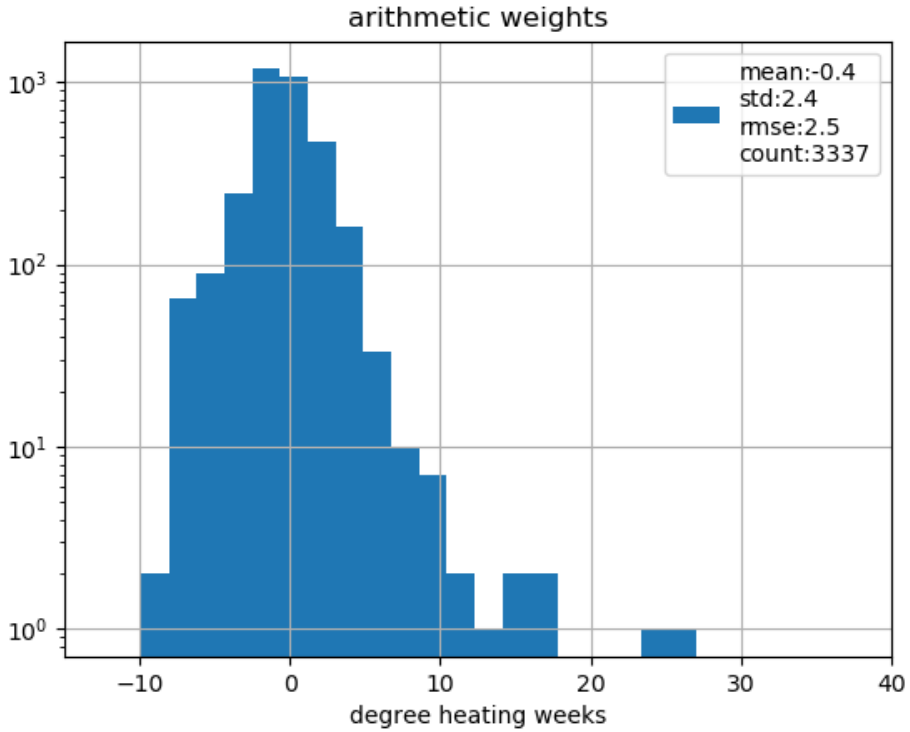
Comparison metric needed: We use the annual-maximum DHW

We are developing a spatial covariance model to calculate weights

As a guide we use simple arithmetic model weights:

$\varphi_{ij} = 1/|M_{ij} - M_{iObs}|$ j=1...K, i=1...N, where M are the mean of annual-max DHW over a time period





Plots show diffs of model and obs. M for flat and weighted model ensembles.

φ_{ij} estimated for 1980-1999
M calculated for 2005-2014

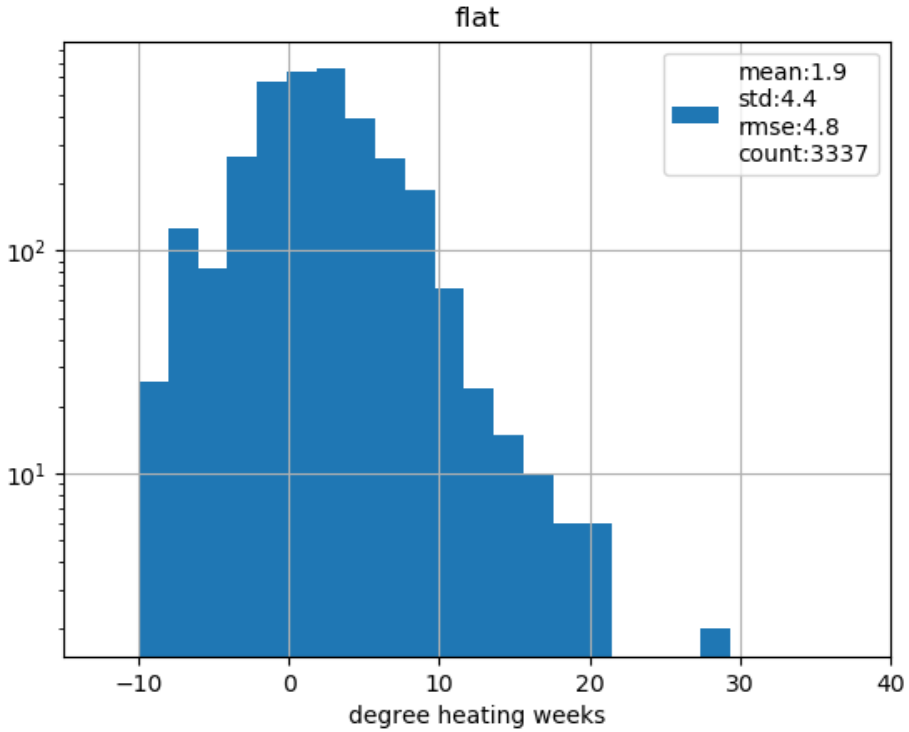
Spatial Model Weighting

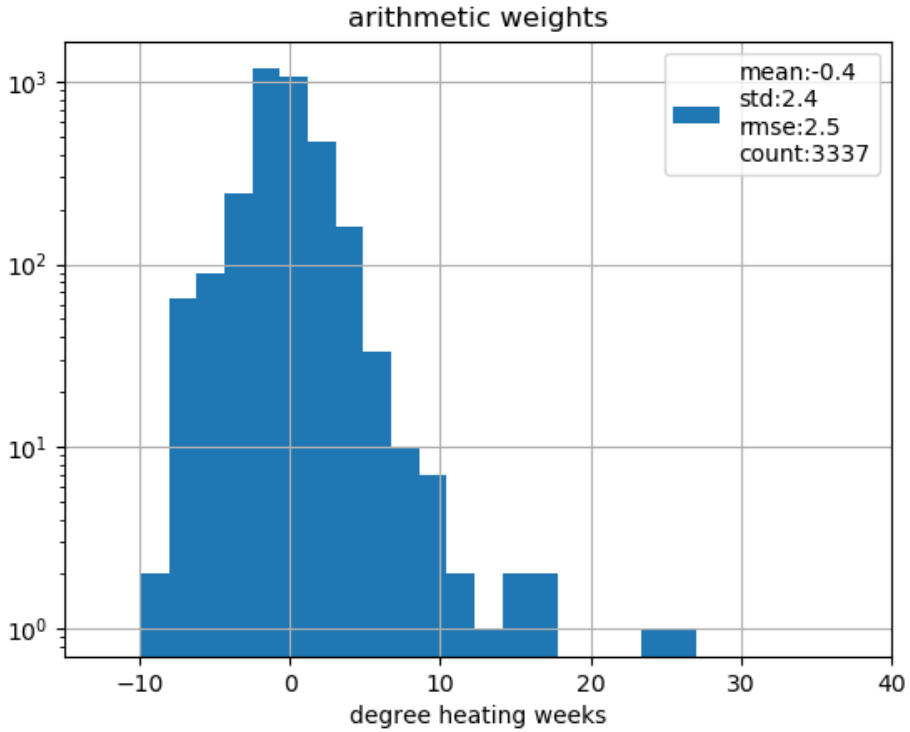
Jet Propulsion Laboratory
California Institute of Technology

U. Cincinnati team (led by Emily Kang) is creating a Bayesian Hierarchical Model for weighting

They have developed the theoretical basis and the code

- Incorporates spatial covariance of near-neighbor pixels
- Currently testing on synthetic data
- Once it is tested, compare to arithmetic weights, redo the 2022 analysis with weighting





Plots show diffs of model and obs. *M* for flat and weighted model ensembles.

φ_{ij} estimated for 1980-1999
M calculated for 2005-2014

Statistical Downscaling

Jet Propulsion Laboratory
California Institute of Technology

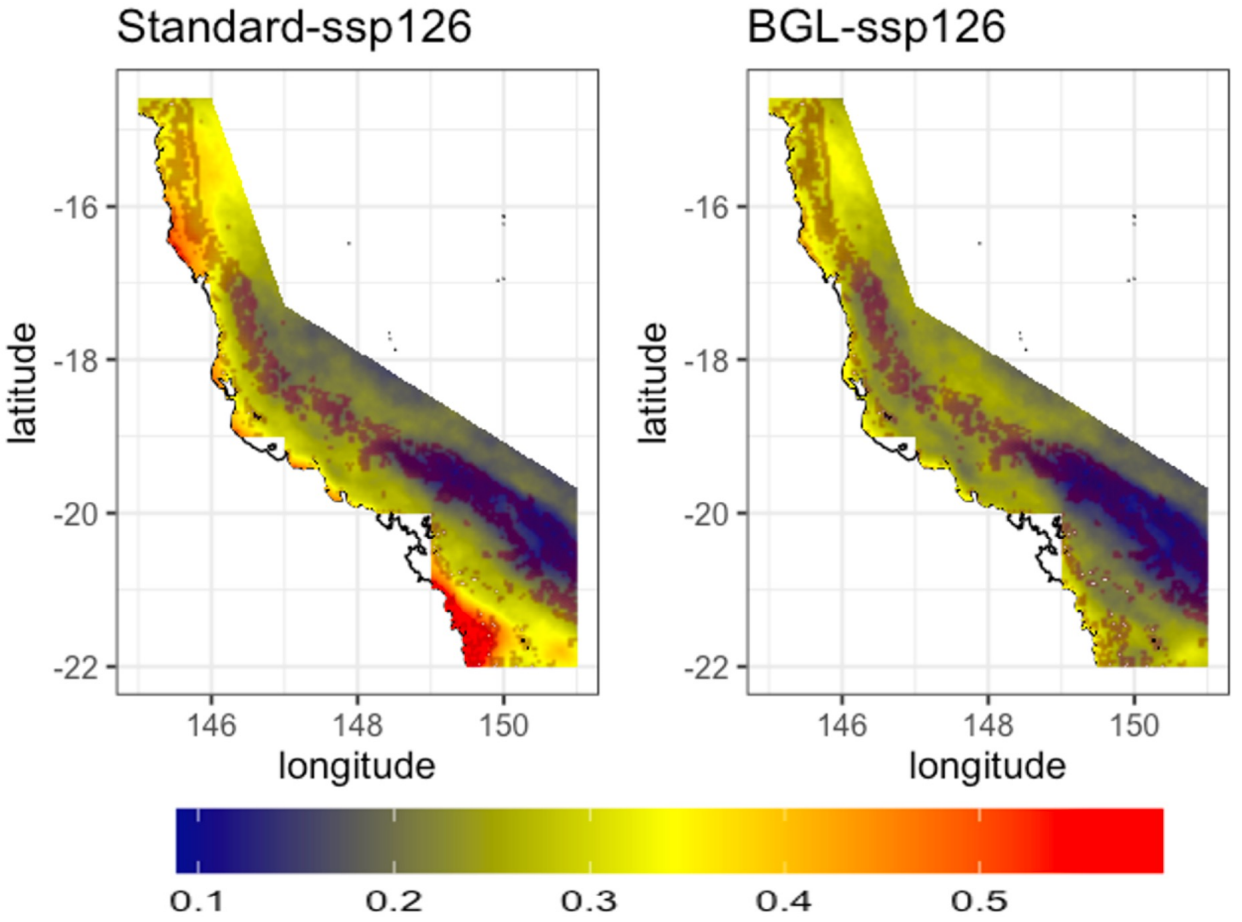
GCM outputs are at ~100 km scale

We downscale SST projections with 1 km JPL MUR observations

Standard downscaling:

1. At each coarse-scale cell time series, and for each month, subtract climatology
2. Interpolate this coarse-scale anomaly time series onto the fine-scale grid
3. At each fine-scale pixel, for each month, add the MUR climatology.

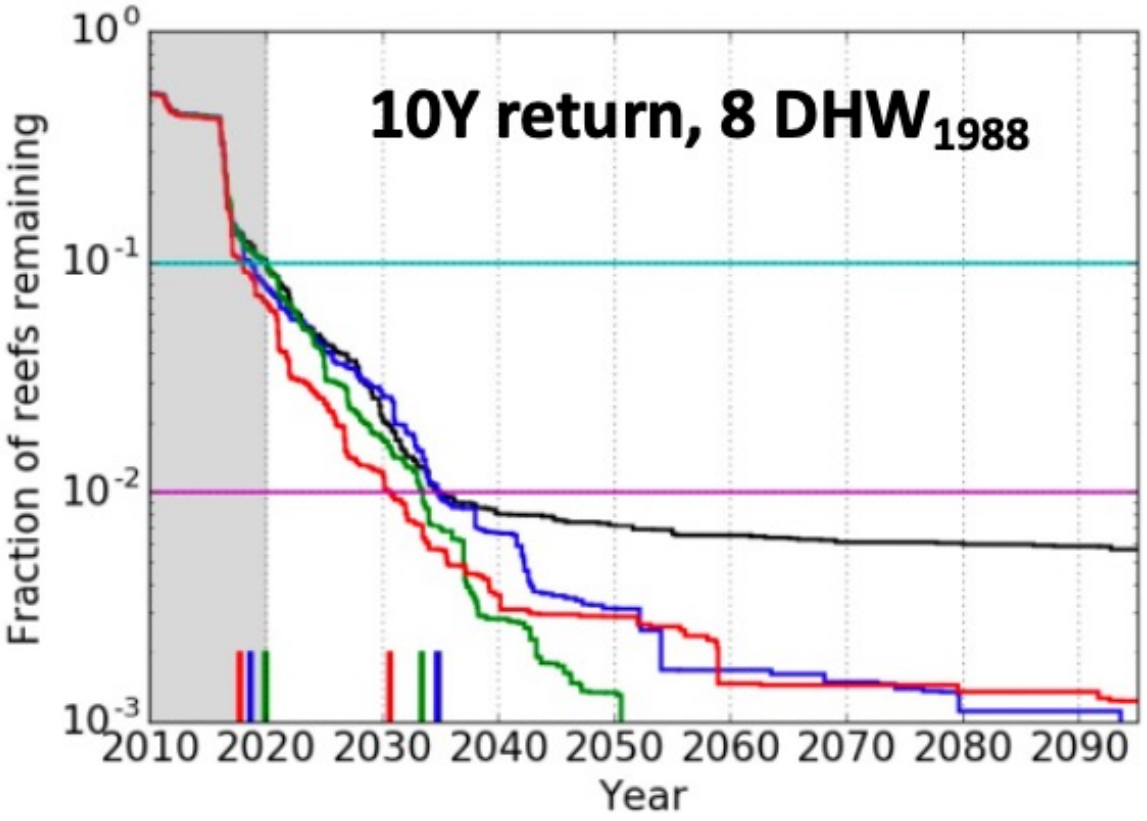
BGL downscaling method models spatial dependence structure across coarse and fine scales applying Basis Graphical Lasso. Ekanayaka et al., 2023

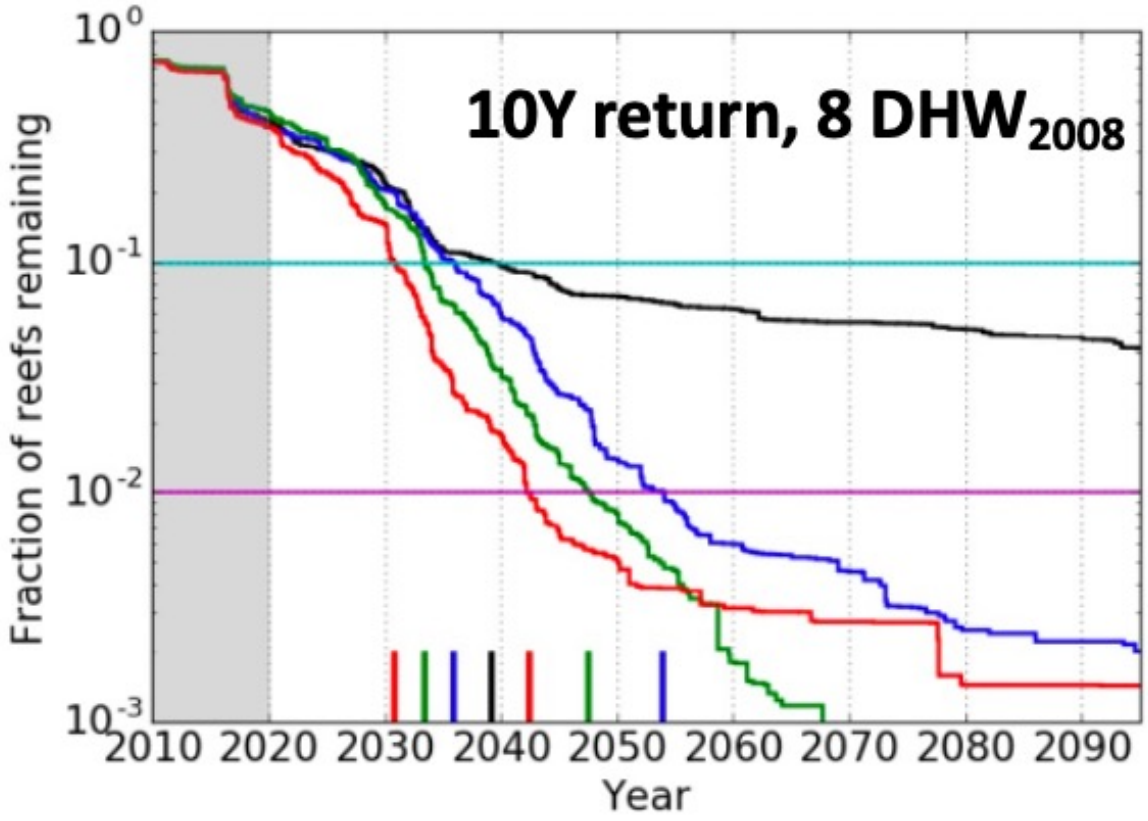


Standard and BGL downscaling MSE (°C^2) estimated from validation against withheld 2018-2020 MUR data in the central GBR. Reefs are indicated by brown mask. Note improvement in near-coastal regions. Averaged over reefs, standard had MSE of 0.25°C^2 while BGL had MSE of 0.17°C^2, a reduction of 31%.

Cumulative histograms (unweighted)

Jet Propulsion Laboratory
California Institute of Technology





SSP126 (black)
SSP245 (blue)
SSP370 (green)
SSP585 (red)

Kalmus et al. (2022)

Thermal departure milestones (unweighted)

Jet Propulsion Laboratory
California Institute of Technology

Projected years and GMSTAs after which fewer than the stated percentage of 1 km reef locations remain below the thermal thresholds, for a return timescale of 10 years

	8 DHW_{2008}			8 DHW_{1998}			8 DHW_{1988}		
	30%	10%	1%	30%	10%	1%	30%	10%	1%
	Year in twenty-first century								
SSP126	25	39	—	17	29	—	16	20	34
SSP245	25	35	53	17	28	44	16	18	34
SSP370	26	33	47	19	27	39	16	19	33
SSP585	22	30	42	16	25	36	16	17	30
	Global mean surface temperature anomaly (°C)								
SSP245	1.4	1.7	1.9	1.2	1.5	1.8	1.1	1.2	1.7
SSP370	1.4	1.7	1.9	1.2	1.5	1.8	1.1	1.2	1.6
SSP585	1.3	1.5	1.9	1.1	1.4	1.7	1.1	1.2	1.5

90% TD10Y by 2020

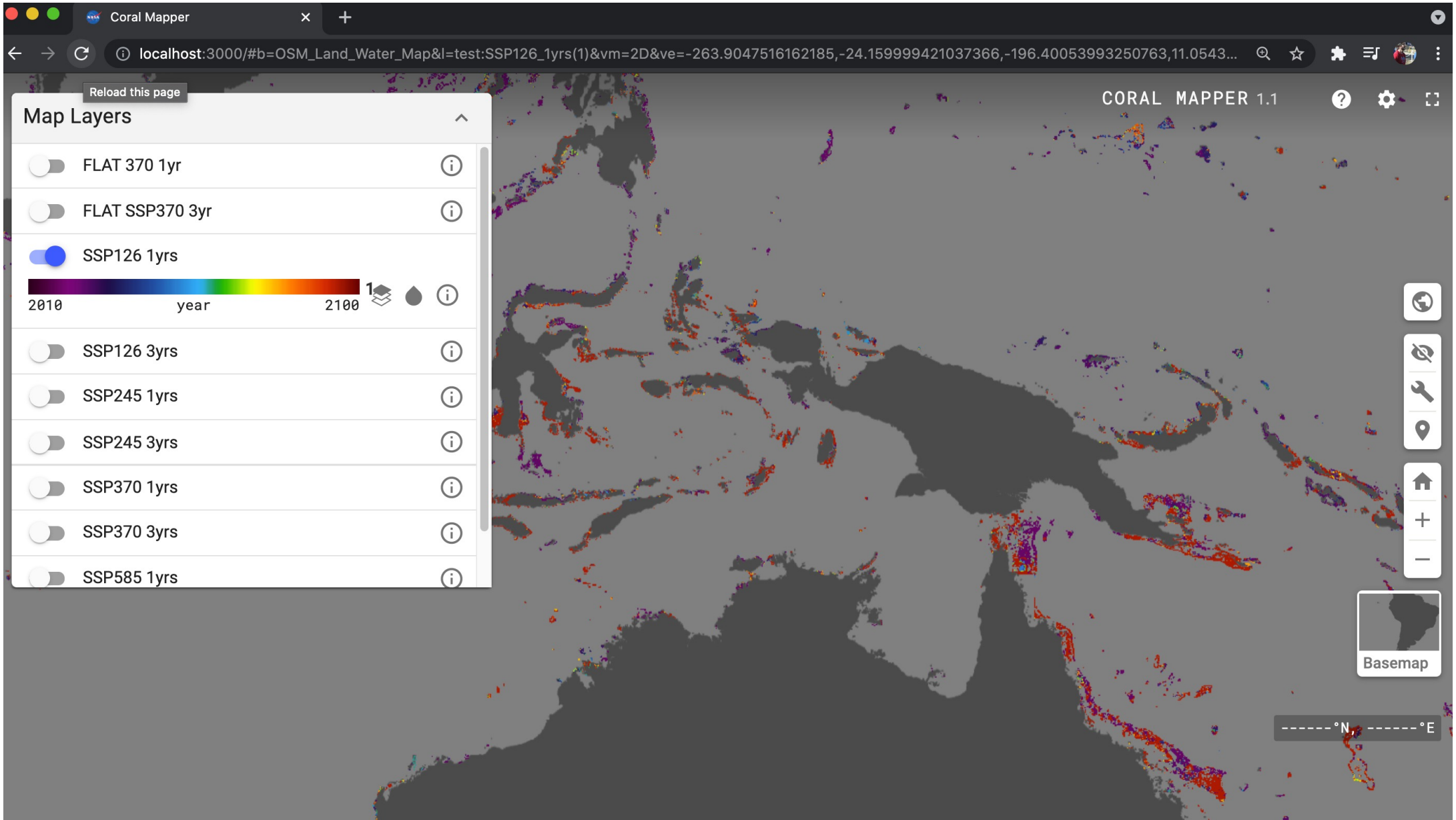
99% TD10Y by 2044
SSP126 avoids this

2°C appears to be a limit: basically no locations <8 DHW

Kalmus et al. (2022)

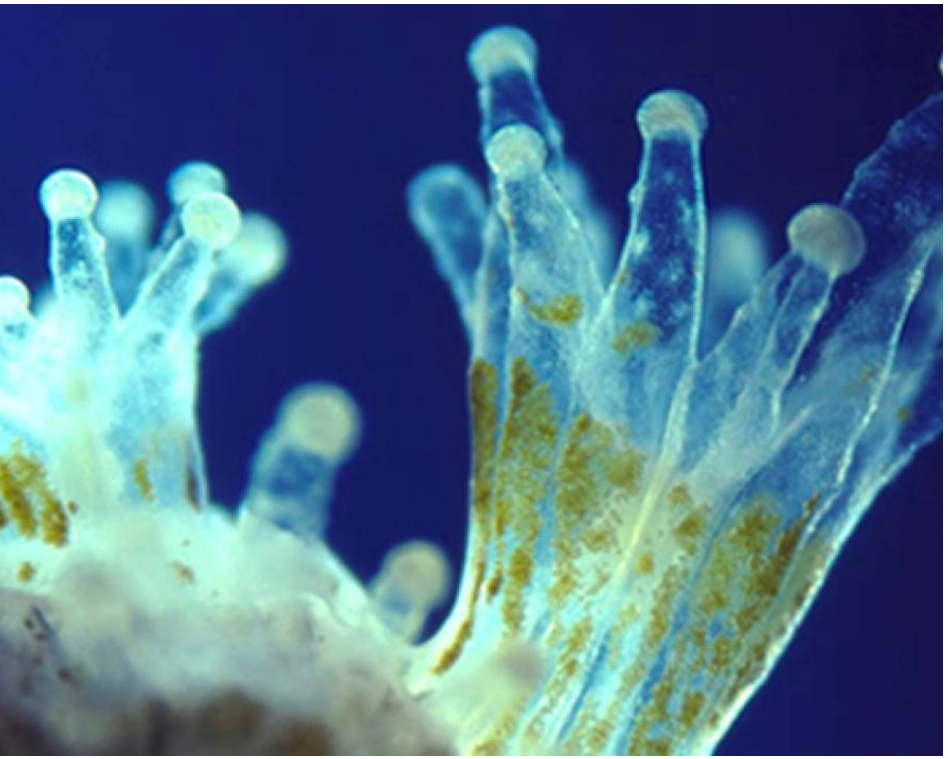
Visualization tool

Jet Propulsion Laboratory
California Institute of Technology



Project Challenges

Jet Propulsion Laboratory
California Institute of Technology



Smithsonian

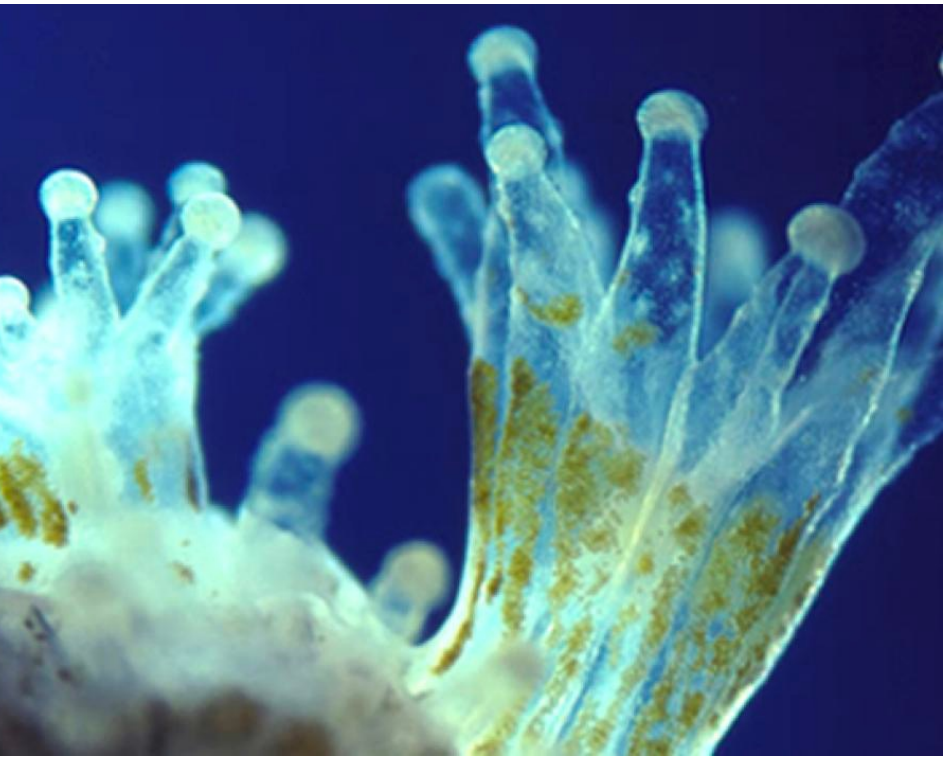
Public hosting of the data visualizer

Slow development of the weighting algorithm

Stakeholder relationships

Future and ongoing work

Jet Propulsion Laboratory
California Institute of Technology



Smithsonian

Spatial model weighting

- Redo 2022 analysis
- Compare flat and weighted results

Model using bleaching remote sensing data

- Replace global DHW threshold
- Add additional predictor variables

Apply and advance design and methods in context of other ecosystems:

- New Advanced Information Systems Technology (AIST) project: “Ecological Projection Analytic Collaborative Framework (EcoPro)”
- New Health and Air Quality (HAQ) project: “Neighborhood-Scale Extreme Humid Heat Health Impacts”

Conclusion

Jet Propulsion Laboratory
California Institute of Technology

- Model weighting appears promising for increasing accuracy of projections
- We are currently developing Spatial Model Weighting

- We project over 91% of coral reefs will now experience severe-bleaching-level ocean heat recurring at least once every 10 years
- We project over 99% of reefs will experience severe-bleaching-level ocean heat at least twice per ten years by 2036 under SSP3-7.0
- We find SSP1-2.6 to be the only scenario not consistent with near-complete global severe degradation or loss of coral reefs
- 2°C may be hard limit for coral reefs as we know them today

Kalmus et al. (2022), AGU Earth's Future
"Past the Precipice? Projected Coral Habitability Under Global Heating"